United States Patent [19]

Matsuda et al.

[11] 3,813,631

[45] May 28, 1974

[54] **HIGH RESISTANCE RESISTOR DEVICE FOR DC HIGH VOLTAGE CIRCUITS**

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[22] Filed: **July 25, 1973**

[21] Appl. No.: **382,336**

[30] **Foreign Application Priority Data**

Aug. 9, 1972 Japan 47-79123

Aug. 9, 1972 Japan 47-79124

[52] **U.S. Cl.**................ **338/320,** 338/257, 338/260, 338/295

[51] **Int. Cl.**.. **H01c 1/02**

[58] **Field of Search** 338/257, 260, 295, 320

[56] **References Cited**

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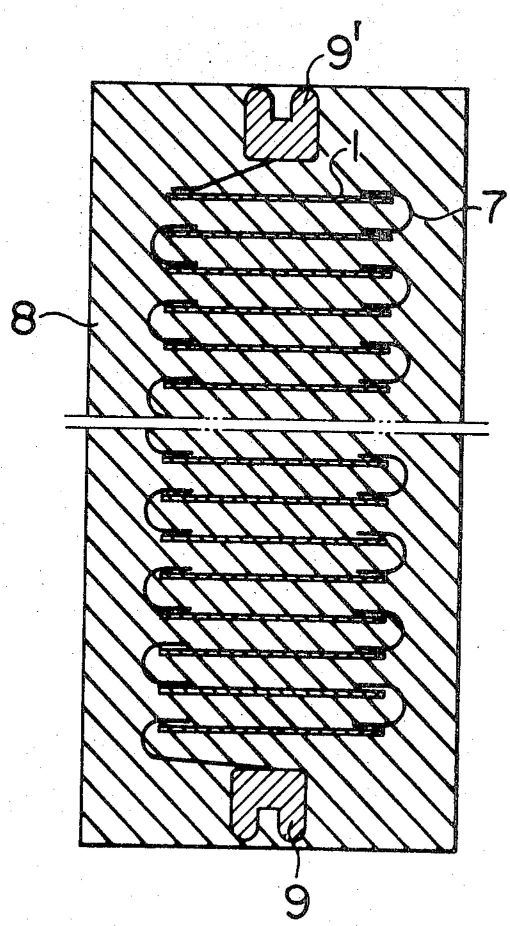
[57] **ABSTRACT**

A high resistance resistor device for d.c. high voltage circuits in which a suitable number of film resistor elements required for providing the desired resistance value are electrically connected in series and are molded as a unit with an adhesive thermo-setting resin composition. Each film resistor element includes a linear resistive film consisting of a plurality of rectilinear portions formed on a refractory insulating substrate and a plurality of portions connecting the opposite ends of the rectilinear portions in series. The resistor film is coated with a glass layer for protection. These film resistor elements are superposed and spaced from each other by a predetermined distance, and the adhesive thermo-setting resin composition covers the surfaces of the film resistor elements for electrically insulating the resistive films of these elements from each other.

5 Claims, 7 Drawing Figures



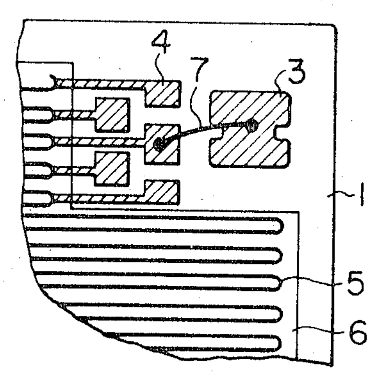


FIG. 1

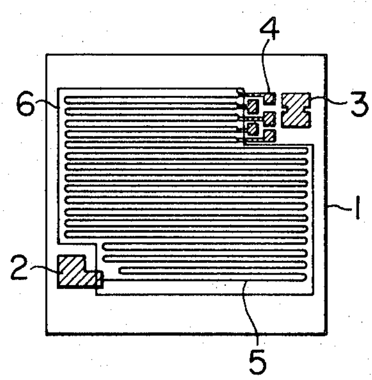


FIG. 2

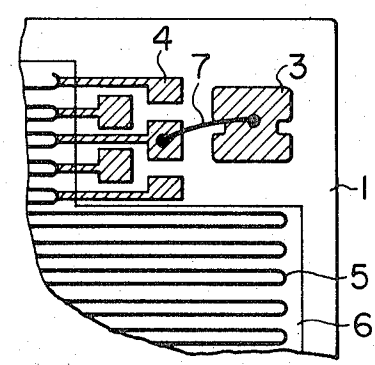


FIG. 3

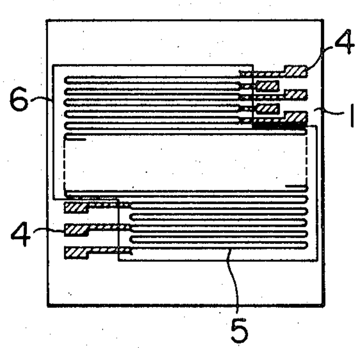


FIG. 4

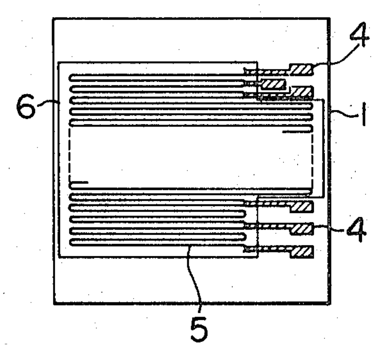


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FIG. 5

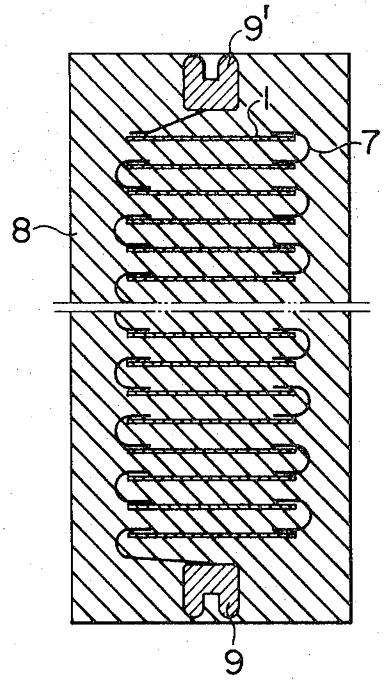


FIG. 6

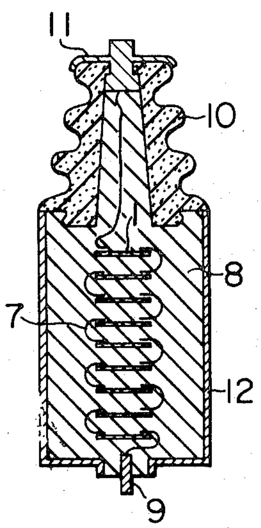
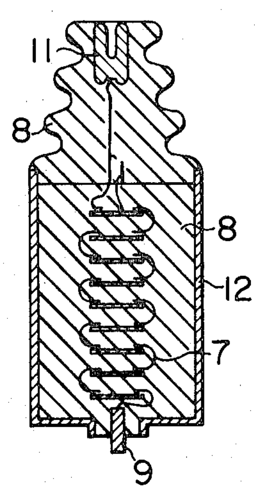


FIG. 7



HIGH RESISTANCE RESISTOR DEVICE FOR DC HIGH VOLTAGE CIRCUITS

This invention relates to a high resistance resistor device for d.c. high voltage circuits.

High stability is demanded for a d.c. high voltage power supply for use in, for example, electron probe micro analyzers, mass spectrometers and electron microscopes. In such a power supply, a high resistance resistor device is used as a reference resistor and is disposed on the high voltage side of the power supply especially when the d.c. high voltage is measured by means of division by resistances. This reference resistor is generally used in conjunction with a detecting resistor having a resistance value for lower than the resistance value thereof for detecting the divided voltage, and the power supply voltage is controlled on the basis of the detected voltage so as to obtain a stable high voltage output.

These two resistors serving as the dividing resistors tend to produce noise such as thermal noise, current noise, and various other noise may be externally induced due to the application of the high voltage. Undesirable fluctuations of the d.c. high voltage output occur largely due to such noises and due to drift owing to voltage or temperature variations. Therefore, it is very important to prevent various noise produced by these resistors in order to stabilize the d.c. high voltage output.

Detecting resistors used in the power supplies of the kind above described have generally a medium resistance value and a low voltage is applied thereto. For example, the voltage applied to such resistor is lower than 100 volts, and the resistance value thereof is of the order of 0.1 to 1 MΩ. Thus, it is easy to obtain a detecting resistor whose noise voltage is of the order of 0.1 μV/V. Further, due to the fact that the voltage applied to the detecting resistor is quite low, the electric field around the resistor is weak and the resistor can be easily electrostatically shielded. Thus, externally induced noises can be sufficiently suppressed.

On the other hand, reference resistors are generally applied with a high voltage of 50 to 200 kV and have a high resistance value of 500 to 2,000 MΩ in order to minimize the electrical loss. Conventional resistors of this kind comprise generally a resistive film of carbon or metal formed spirally on the surface of a rod-shaped base of refractory and electrical insulating material. According to the present printing technique and properties of resistive materials, however, it is difficult to form a spiral resistive film of narrow strip width and narrow spacing between the strips, resulting inevitably in a bulky resistor. When a rod-shaped base of refractory and electrical insulating material is used to obtain a film resistor having a resistance value of 1,000 MΩ according to the present printing technique, the length of the resistor would become quite long or of the order of 40 to 50 cm. Sufficient insulation must be provided for the resistor of this kind due to the fact that a high voltage is applied thereto, and insulating means such as insulating paper impregnated with insulating oil is wound around the resistor for eliminating adverse effects due to disturbance. It has been inevitable that this insulating structure leads necessarily to the bulkiness of the resistor.

Further, a highly precise resistance value is demanded for the resistor of this kind in order to obtain an accurate voltage at the d.c. high voltage output. Furthermore, uniform electric field distribution is demanded for the resistor of this kind due to the fact that a high voltage is applied thereto. However, in the case of the resistor having such a high resistance, it is not easy to obtain a resistance value which is exactly equal to a predetermined setting. It is common practice to adjust the resistance to the required value by cutting away a part of the resistive film or applying a conductive paint while continuously measuring the resistance value of the resistor. However, due to the fact that such precision processing leads to an increase in the cost of manufacture and it is extremely difficult to exactly measure such a high resistance such as 1,000 MΩ, it has not been possible to obtain reliably those resistors having the desired resistance value.

It is therefore an object of the present invention to provide a high resistance resistor device for d.c. high voltage circuits which is smaller than hitherto in size and has an accurate resistance value.

Another object of the present invention is to provide a high voltage resistor device for d.c. high voltage circuits which can operate without producing noise of any substantial level.

Still another object of the present invention is to provide a high voltage resistor device for d.c. high voltage circuits which has a high dielectric strength and a high mechanical strength and is resistive to corrosion and in which the electric field distribution is uniform.

Yet another object of the present invention is to provide a high resistance resistor device for d.c. high voltage circuits whose resistance value can be easily adjusted and whose quality control can be easily attained during the manufacturing process.

Other objects, features and advantages of the present invention will be apparent from the following detailed description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic plan view of a film resistor element employed in a high resistance resistor device according to the present invention;

FIG. 2 is an enlarged plan view showing the detail of a resistance value adjusting portion in the film resistor element shown in FIG. 1;

FIGS. 3 and 4 are schematic plan views showing modifications of the film resistor element shown in FIG. 1;

FIG. 5 is a schematic longitudinal section of a high resistance resistor device of the present invention which is obtained by connecting a plurality of film resistor elements as shown in FIG. 1, 3 or 4 in series with each other and molding the assembly with an adhesive thermo-setting resin; and

FIGS. 6 and 7 are schematic longitudinal sections of the high resistance device of the present invention which is electrostatically shielded by shielding means.

The present invention provides a high resistance resistor device which is obtained by connecting a plurality of film resistor elements as shown in FIG. 1, 3 or 4 in series with each other and molding the assembly with an adhesive thermo-setting resin as seen in FIG. 5.

A flat base of refractory and electrical insulating material is used for forming the film resistor element employed in the present invention. The use of the flat base plate is advantageous in that precise printing can be applied even with the present printing technique, and consequently, a resistive film having a maximum resistance value can be formed on the surface of the base plate by utilizing the surface of the base plate effectively as much as possible. Therefore, the size of the high resistance resistor device can be reduced to a minimum due to the fact that the resistance value of the resistive film on each base plate can be increased and the number of the base plates required for obtaining the desired total resistance value can be reduced to a minimum. In the present invention, the resistive film is formed on one of the surfaces of the base plate. Although the resistive film might be printed on both the surfaces of the base plate, difficulty is encountered in preventing damage to the resistive films printed on the opposite surfaces of the base plate and it is also difficult to eliminate undesirable fluctuations of the resistance value from the manufacturing point of view.

The film resistor element employed in the present invention has a resistance value of the order of several ten megohms and is provided with a plurality of terminals adjacent to at least one end portion of the resistive film for adjusting the resistance value as shown in, for example, FIG. 2. Possible variations of the resistance value during manufacture and required precision in the resistance value are previously taken into consideration to limit the range of adjustment of the resistance value so that the adjustment of the resistance value can be sufficiently practically attained by merely selecting one of these terminals without requiring any precision processing such as cutting of the film or application of a conductive paint. This is a significant advantage because the resistance value of individual film resistor elements can be easily controlled. Thus, when a plurality of such film resistor elements are connected in series by the number which provides the desired total resistance value of a high resistance resistor device for d.c. high voltage circuits (referred to hereinafter as a high resistance resistor device for the sake of simplicity), the desired resistance value can be obtained with high precision and the manufacturing cost can be greatly reduced. This is because the resistance value of each film resistor element can be exactly measured due to the fact that the resistance value thereof is of the order of several ten megohms as above described. Therefore, the resistance values of the individual film resistor elements constituting the high resistance resistor device may be merely added together to obtain the desired total resistance value with high precision. Further, the high resistance resistor device is composed of the film resistor elements whose resistance value is controlled to lie within the predetermined range. This is advantageous in that uniform electric field distribution can be obtained. If the high resistance resistor device includes portions in which the electric field may concentrate, it is defective in that externally induced noise is increased and dielectric breakdown tends to occur.

One practical form of the film resistor element employed in the present invention will be described with reference to FIGS. 1 and 2.

A conductive paste of Pd-Ag-glass was printed on one surface of an electrical insulating base 1 of alumina having a size of 50 mm × 50 mm × 0.6 mm and was fired so as to provide a plurality of terminals 2, 3 and 4 on the base plate 1 as shown in FIG. 1. Then, a paste of RuO_2-Ag was printed on the same surface of the base plate 1 by screen printing and was fired for about 10 minutes at about 800°C for forming a resistive film 5 consisting of a plurality of strips on the base 1 as shown in FIG. 1. The width of the strips constituting the resistive film 5 was selected to be about 0.5 mm and the total length of the resistive film 5 was selected to be about 2 m so that a voltage of 10 kV can be applied to this film resistor element. In order to limit the resistance value of the film resistor element to a predetermined range, possible variations of the resistance value during manufacture and required precision in the resistance value were previously taken into consideration and five adjusting terminals 4 were provided as shown in FIG. 2. The difference between the resistance values of the film portions connected to the adjacent ones of these adjusting terminals 4 was about 1 MΩ. Then, the most suitable terminal was selected from these five terminals 4 and was connected to the terminal 3 by a soldered soft copper wire 7 having a diameter of 0.4 mm so as to obtain the desired resistance value, 40 MΩ, of the film resistor element. The film resistor elements obtained in this manner had a resistance value of 40 MΩ ± 3 MΩ and the reject rate was less than 1 percent. The manufacturing cost could be greatly reduced due to the fact that the adjustment of the resistance value could be easily attained compared with the prior art method of adjustment such as film cutting or conductive paint application.

If the terminals for adjusting the resistance value were not provided, the percentage with which the resistance value can be limited to lie within the range of 40 MΩ ± 3 MΩ is of the order of 50 percent and an extremely bad yield rate results unless precision processing such as film cutting is resorted to.

In the film resistor element shown in FIG. 1, five adjusting terminals 4 are disposed adjacent to one of the end portions of the resistive film 5 for adjusting the resistance value. However, these adjusting terminals 4 may be disposed adjacent to the opposite and portions of the resistive film 5 as shown in FIG. 3 or 4 and the number of such terminals 4 is not in any way limited to five. Further, although the connection terminals 2 and 3 of the film resistor element are disposed at the diagonally opposite positions on the refractory, insulating base plate 1 in FIG. 1, their positions are in no way limited to those shown in FIG. 1. These terminals 2 and 3 may be disposed on the same side of the film resistor element or may not be especially provided as shown in FIGS. 3 and 4.

It is apparent that, when a film resistor element obtained by forming a spiral resistive film on a single rod-shaped base of electrical insulating material is used to constitute a high resistance resistor device having a high resistance value of more than 500 MΩ, it is impossible to employ an arrangement as shown in FIG. 5 in which a plurality of flat resistor elements are superposed or laminated to constitute a high resistance device. This leads inevitably to an increase in the size of the insulating base plate and the quality control of the insulating base plate itself is difficult to attain. Further, this spiral film type high resistance resistor device is economically disadvantageous in that, even when a slight defect in the resistor element may adversely affect the operating characteristic of the high resistance resistor device, such a defective portion cannot solely be replaced by a sound portion.

It is preferable from various aspects that the film resistor element in the device according to the present invention has a size of the order of 50 mm × 50 mm as described before. An insulating base plate which is free from any warping and uneveness is required especially when the resistive film is formed by printing technique. Warping tends to occur in the insulating base plate when the size of the insulating base plate is greater than that above described. The resistance value of the order of several ten megohms is especially preferable from the viewpoint of insulation too since the strength of the electric field applied to each resistor element is of the order of 10 to 20 kV when a plurality of such resistor elements are used to consitute a high resistance resistor device described later. There are various patterns for the resistive film. However, the pattern shown in FIGS. 1 to 4 is most ideal in that the base plate surface can be most effectively utilized, electrical connection can be easily attained and electric field distribution in the resistor element is uniform.

The refractory and electrical insulating material forming the base plate of the film resistor element employed in the present invention may, for example, be alumina, steatite, mullite, forsterite, berylia or quartz glass which can withstand a temperature higher than 1,000°C. Suitable materials of the resistive film may, for example, be a mixture of powders of a glass and a resistive substance such as Pd-Ag mixture, RuO_2, RuO_2-Ag compound or Tl_2O_3. This mixture is prepared by mixing the powder mixture with a suitable liquid such as organic solvent or ethyl cellulose. The paste is prepared by mixing and kneading the above materials. The resistive film pattern may be provided by printing the paste on the insulating base plate to a thickness of 10 to 30 μ as by screen printing and then firing the paste at about 600°C to 900°C for about 5 to 20 minutes. It is preferred that the strips of the resistive film have a width of the order of 0.5 mm and the adjacent strips of the resistive film are spaced apart by about 0.5 mm when the precision of the screen printing is taken into consideration.

A plurality of film resistor elements obtained in a manner as above described are connected in series with each other by the number which is required for providing the desired total resistance value as shown in FIG. 5, and the assembly is molded with an adhesive thermo-setting resin or resin composition. The resin used for molding must be such that it covers the brittleness of the insulating base plate of the resistor element and has a satisfactory adhesiveness and defects including voids do not occur in the molding. Thermo-setting resins are suitable for this purpose. For example, a combination of an alicyclic type, bisphenol type or novolak type epoxy resin and a curing agent such as an acid anhydride or amino compound may be used. Preferred alicyclic type epoxy resins include vinyl cyclohexene di-epoxide, preferred bisphenol type epoxy resins include diglycidyl ether of bisphenol A, and preferred novolak type epoxy resins include cresol novolak and phenol novolak. Preferred acid anhydride curing agents include tetrahydrophthalic anhydride and preferred amino compound curing agents include tetraethylene pentamine, diaminodiphenylmethane and diethyltetramine. The insulating base plate may be destroyed or cracks may develop in the cured resin due to the stress resulting from the difference between the coefficient of linear expansion of the adhesive thermo-setting resin and that of the film resistor element. In order to avoid this, more than 1,000 parts by weight of an inorganic filler having a coefficient of linear expansion less than 1×10^{-5}/°C may be blended with 100 parts by weight of the adhesive thermo-setting resin. This inorganic filler may, for example, be zircon, silica, quartz or alumina having a particle diameter less than 1,000 μ. It has been ascertained that no cracks would develop in the cured thermo-setting resin composition and the insulating base would not be destroyed even with a thermal shock test carried out under considerably severe conditions when the difference between the coefficients of linear expansion of the insulating base and cured resin is selected to be less than 1×10^{-5}/°C. In order to provide such difference in the coefficient of linear expansion between the insulating base plate and the cured resin, more than 1,800 parts by weight of the inorganic filler should be blended with 100 parts by weight of the adhesive thermosetting resin. However, blending of more than 2,500 parts by weight of the inorganic filler with the said thermo-setting resin is undesirable in that difficulty is encountered in molding.

It is desirable that a protective layer which may be a thin glass coating as shown by 6 in FIG. 1 is deposited to cover the resistive film 5 of the film resistor element so that the resistive film may not be adversely affected during processing or molding. The glass coating can be obtained by applying a low-melting glass paste (for example, a glass paste number 8185 of duPont in United States) and firing the paste at about 500°C for about 1 minute. The glass coating is preferably 10 to 100 μ thick.

Preferred embodiments of the invention will be described with reference to FIGS. 5, 6 and 7.

Embodiment 1

A glass paste as above described was applied to a film resistor element having a resistance value of 40 MΩ as shown in FIG. 1 so as to provide a protective layer of glass 25 μ thick covering the entire surface of the film resistor element except the terminal portions. Twenty-five such film resistor elements were arranged in predetermined spaced relation as shown in FIG. 5 and were connected in series with each other by connecting the terminals with soldered soft copper leads 7 having a diameter of 0.4 mm. Then, a pair of external connection terminals 9 and 9' of brass were fixed to the opposite ends of the series-connected film resistor elements to obtain an assembly having a total resistance value of 1,000 MΩ.

The assembly was then molded with an epoxy resin composition having a blended ratio as shown in Table 1 and the epoxy resin composition was cured at about 120°C for about 16 hours to obtain a high resistance resistor device according to the present invention. This high resistance resistor device had an external size of about 70 mm × 70 mm × 250 mm.

TABLE 1

Composition	Blended ratio (parts by weight)
Vinyl cyclohexene diepoxy resin (made by Nippon Nitrogen Company, CH 206, epoxy equivalent 75)	100
Filler zircon, particle diameter less than 400 μ (made by Osaka Zircon Company)	2,300
Methyltetrahydrophthalic anhydride (made by Hitachi	

Chemical Company, acid anhydride curing agent NH-200, acid anhydride equivalent 122)	89
2-ethyl-4-methyl imidazole (made by Tore Company, curing accelerator EM-24)	3

In molding the assembly with the epoxy resin composition, the film resistor elements may be maintained in a predetermined position by jigs and the epoxy resin composition may be poured in such an amount which will not embed the jigs in the molding. After carrying out pre-curing at about 80°C for about 2 hours and removing the jigs, the epoxy resin composition may be further poured in such an amount which will completely seal the film resistor elements in the resin molding and heating may be carried out at 120°C for 16 hours for completely curing the epoxy resin composition. In lieu of the two-step molding process above described, the film resistor elements may be supported by jigs made of the epoxy resin composition to be poured, and the assembly may be molded with the epoxy resin composition together with the jigs.

The coefficient of linear expansion of the insulating base of alumina in the high resistance resistor device is 0.8×10^{-5}/°C, while that of the cured epoxy resin composition shown in Table 1 is 1.2×10^{-5}/°C, and thus, there is only a very slight difference of 0.4×10^{-5}/°C therebetween. It will be understood therefore that the high resistance device according to the present invention is compact in construction and has a high dielectric strength, high mechanical strength and high resistance to corrosion.

Electric field distribution between the terminals **9** and **9'** of the high resistance resistor device is uniform due to the fact that the film resistor elements are electrically insulated from each other by the epoxy resin composition and are arranged in uniformly spaced relation. Suppose, for example, that a d.c. voltage of 100 kV is applied across the terminals **9** and **9'** of the high resistance device. In this case, creeping leakage occurring along the surface of the high resistance resistor device can be sufficiently avoided when the terminals **9** and **9'** are spaced apart by more than 20 cm. Thus, the size of the high resistance resistor device can be reduced to less than one-half of conventional devices of this kind.

The high resistance resistor device obtained by the process above described is generally electrostatically shielded when it is used as a reference resistor. Problems which arise in this connection include electrical insulation between the shielding casing and the high voltage terminal. Two forms of such insulation are shown in FIGS. **6** and **7.** In the high resistance resistor device shown in FIG. **6,** a porcelain insulator **10** was molded on the block **8** of the cured epoxy resin composition surrounded by the shielding casing **12** for providing sufficient insulation distance between the high voltage terminal **11** and the shielding casing **12.** Although a porcelain insulator is employed in FIG. **6,** this insulator portion may be of the same material as the block of the cured epoxy resin composition and may be molded in integral relation with the latter.

A conventional high resistance resistor device of this kind was manufactured by preparing a commercially available film resistor element (diameter 50 mm × length 600 mm) having a carbon-resin resistive film spirally coated on a rod-shaped electrical insulating base of alumina, depositing a protective layer of epoxy resin on the resistive film, and winding oil-impregnated paper around the film resistor element for electrostatic shielding. Such a conventional high resistance resistor device was compared with the high resistance resistor device of the present invention shown in FIG. **6.** In the test, these two high resistance resistor devices were immersed in insulating oil having a very slight amount of fine powdery carbon dispersed therein in lieu of dust, and a d.c. voltage of 150 kV was applied thereto for comparing noise and stability.

The test results are shown in Table 2.

TABLE 2

	Present invention	Conventional
Noise	less than 1 μ V/V	3 μ V/V
Voltage fluctuation	less than 1 μ V/V/min.	4 μ V/V min.

It will be seen from Table 2 that both the noise and the voltage fluctuation in the high resistance resistor device of the present invention are less than those in the conventional high resistance device. Thus, when the high resistance resistor device of the present invention is used as a reference resistor in an electron microscope, the resolution of the electron microscope can be improved 1.5 to 2 times that of conventional electron microscopes.

Embodiment 2

Twenty-five film resistor elements each having a resistance value of 40 MΩ as shown in FIG. **1** were connected in series as in the case of Embodiment **1** and the assembly was molded with an elastic polyester resin composition. This elastic polyester resin composition consisted of 100 parts by weight of an unsaturated polyester resin obtained by causing maleic anhydride to react with a polybutadiene having hydrogenated terminal hydroxyl groups (disclosed in United States Patent Application Ser. No. 880,926, filed November 28, 1969, entitled "POLYESTER RESIN AND METHOD OF MANUFACTURING THE SAME"), 35 parts by weight of tert-butyl styrene, and 1 part by weight of dicumil peroxide and 1.2 parts by weight of cobalt naphthenate added as a catalyst. After pouring this polyester resin composition, heat was applied at 80°C for 16 hours for curing the resin composition to obtain a molded high resistance resistor device similar to that shown in FIG. **7.** The polyester resin above described has excellent electrical properties and is sufficiently elastic. Thus, this polyester resin absorbs deformation of resistor elements due to the thermal stress occurring between it and the insulating base of the film resistor element thereby preventing undesirable damage to the resistor elements. Those materials which can attain an effect similar to that attained by the above polyester resin include thermo-setting silicone resins and flexible epoxy resins.

The thermo-setting resin compositions described with reference to Embodiments 1 and 2 may be those generally employed in molding and there is not any especial limitation. However, those resins which show a viscosity higher than 100 poises during molding are undesirable for high voltage applications because voids which are difficult to eliminate tend to occur in the molding, exept when the resin contains a filler.

What we claim is:

1. A high resistance resistor device for d.c. high voltage circuits comprising a plurality of film resistor elements, each said resistor element including a flat base of refractory and electrical insulating material, a linear resistive film consisting of a plurality of rectilinear portions disposed in parallel with one another on one surface of said base and a plurality of portions connecting said rectilinear portions in series with each other, and a pair of terminal portions disposed at the opposite ends of said resistive film, said resistor elements being superposed one over another so as to be spaced apart from each other by a predetermined distance, said resistive films being electrically connected in series at said terminal portions by suitable connecting means, the opposite terminals of the series-connected resistive films on the outer-most insulating bases being electrically connected to a pair of terminals respectively for connection to an external d.c. voltage power supply; and a solid insulation of a cured adhesive thermo-setting resin, said solid insulation serving as to insulate electrically said resistor elements from each other by being intimately bonded to the surface of said resistor elements without defining even a minute void therebetween, and to prevent substantially any displacement of said resistor elements relative to each other and to electrically insulate said connecting means.

2. A high resistance resistor device as claimed in claim 1, wherein a protective coating of glass is formed on said resistive film of each said film resistor element.

3. A high resistance resistor device as claimed in claim 1, wherein said thermo-setting resin comprises 100 parts by weight of a thermo-setting resin and 1,000 to 2,500 parts by weight of an electrical insulating inorganic filler.

4. A high resistance device as claimed in claim 1, wherein the difference between the coefficient of linear expansion of said refractory and electrical insulating base of said film resistor element and that of said cured thermo-setting resin composition is selected to be less than $1 \times 10^{-5}/°C$.

5. A high resistance device as claimed in claim 1, wherein said film resistor element includes at least two resistance adjusting terminals adjacent to at least one end portion of said resistive film.

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